HKCMA Technical Seminar 2019

Sand for Concrete, Mortar and Reclamation

A.K.H. Kwan
Department of Civil Engineering
The University of Hong Kong, Hong Kong

Overview

Shortage of river sand supply in Asia

Hong Kong and Shen Zhen:

- In Hong Kong, all river sand imported from Mainland
- But Shen Zhen also uses a lot of river sand in concrete and mortar
- Dredging faster than deposition; gradual depletion; river banks becoming unstable
- Newly deposited sand does not have good shape (no time for natural attrition)
- Shen Zhen started using washed sea sand; high risk of chloride contamination
- Mainland started production of manufactured sand (also called M-sand)

Overview (Cont'd)

Shortage of river sand supply in Asia:

Singapore:

- Speaker visited Singapore in 04/2017 to help solve their river sand shortage problem
- Singapore Government came in 09/2017 to consult Hong Kong Government
- Singapore Government came again in 05/2019 to consult CIC and industry
- Have been using river sand in both concrete and mortar until now
- Malaysia and Indonesia limiting supply of river sand
- Have to find alternative source of fine aggregate or start using crushed rock fine
- Thinking of what standard to follow

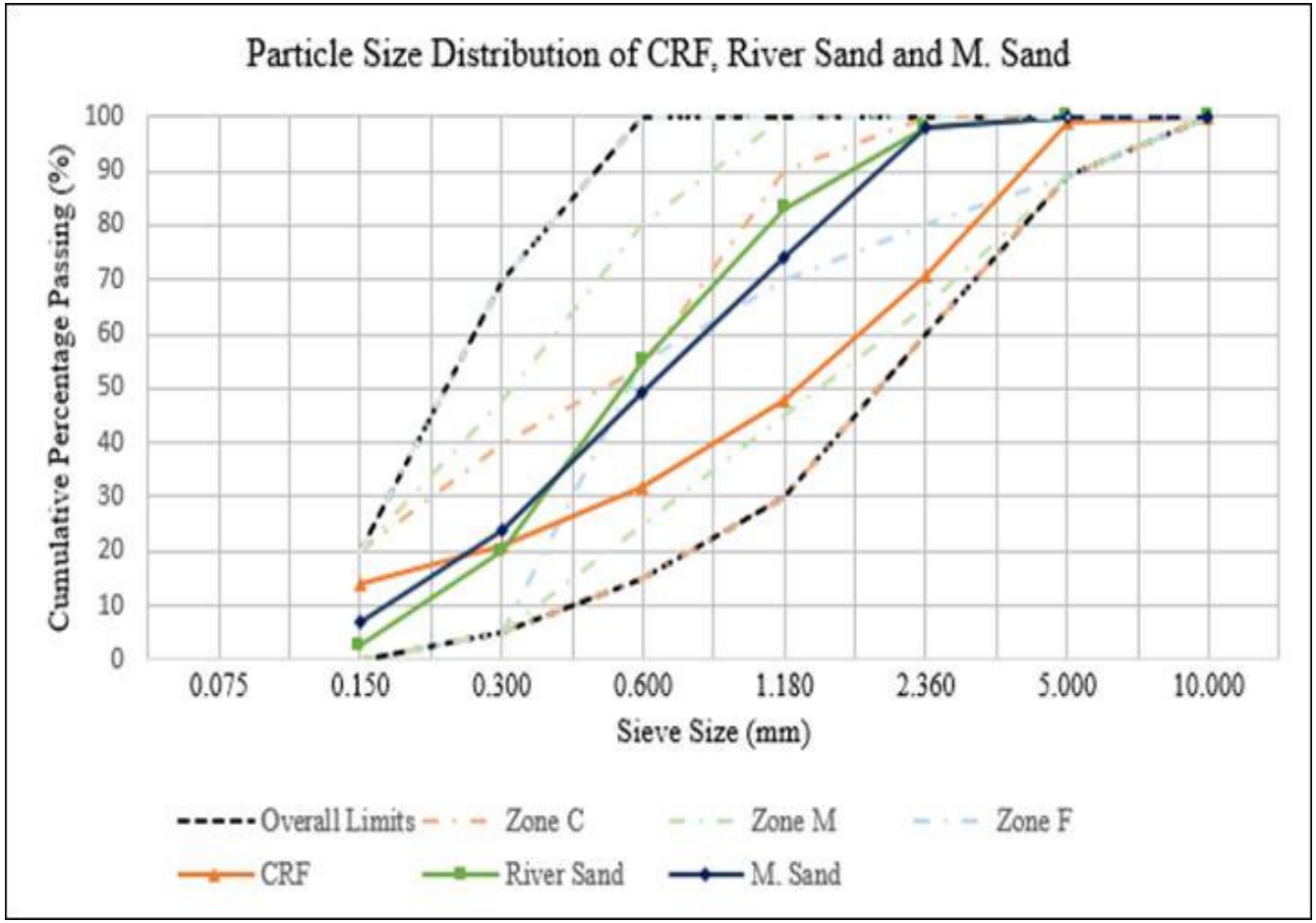
Overview (Cont'd)

Shortage of sea sand supply in Asia

Sea sand for reclamation:

- Sea sand is being used as reclamation fill for CLK Airport 3rd Runway Project
- Limited supplies from Mainland China and South East Asia
- High demand + limited supply leads to high cost of sea sand
- Shortage of reclamation fill is causing delay to 3rd Runway Project
- Started using C&D Waste and M-sand
- High fines content in reclamation fill could cause suspended solids pollution

Overview (Cont'd)



Aggregate for concrete

Desired properties of aggregate in concrete

- The aggregate typically makes up about 2/3 of volume of concrete
- Fills up a large portion of the volume to reduce amount of cement paste needed
- Provide dimensional stability because of high elastic modulus, low drying shrinkage and no heat generation during curing
- Packing density is important because a higher packing density means a smaller volume of voids to be filled with cement paste
- With higher packing density, the amount of cement paste needed would be decreased
- And concrete with higher dimensional stability, lower carbon footprint and lower material cost could be produced

Aggregate for concrete (Cont'd)

Desired properties of aggregate in concrete

- Fine to total aggregate ratio usually within the range of 0.30 to 0.50
- To maximize packing density, the fine aggregate should be just enough to fill the voids in the coarse aggregate; hence there is an optimum fine to total aggregate ratio
- Such optimum fine to total aggregate ratio can be determined by trial blending and testing
- However, there are also voids in the fine aggregate and thus the packing density of the total aggregate is highly dependent on the packing density of the fine aggregate

Aggregate for concrete (Cont'd)

Desired properties of aggregate in concrete

- The main factors affecting the packing density are particle shape and size distribution
- The particle shape may be classified into: well-rounded, rounded, sub-rounded, sub-angular and angular
- A higher roundness (or lower angularity) would lead to a higher packing density or vice versa
- The optimum particle size distribution is one such that the medium size particles would fill into the voids of larger size particles and the smaller size particles would fill into the voids of medium size particles
- A broader size range would generally lead to a higher packing density

Aggregate for concrete (Cont'd)

Desired properties of aggregate in concrete

- A fine aggregate with rounded shape and broad size range is better
- To provide workability, the aggregate particles need to be coated with cement paste for lubrication
- Hence, the cement paste is not just to fill the voids in the aggregate but also to provide paste films coating the aggregate particles
- The amount of cement paste needed to provide paste films is proportional to the total surface area of aggregate
- Since the fine aggregate has a larger specific surface area, it has a greater effect than the coarse aggregate on the paste demand
- A fine aggregate with higher fines content requires more cement paste for coating

Aggregate for concrete (Cont'd)

Desired properties of aggregate in concrete

- An ideal fine aggregate is one that has rounded shape, high packing density and small specific surface area
- The fines content in the fine aggregate (particles finer than 75 μm) would increase the packing density but would also increase the specific surface area
- Hence, the fines content in fine aggregate is a two-edged sword
- There should be some fines to fill the voids so as to increase the packing density but the fines content must not excessively increase the specific surface area
- In theory, there is a certain optimum fines content for best overall performance

Aggregate for concrete (Cont'd)

Does the fines content contain harmful materials?

- In some standards, e.g. the Chinese Standard, the fines content is called clay content, as if the fines are always clay and thus harmful
- Whether the fines content contains substantial amount of clay may be checked by the methylene blue (MB) test
- If the MB value is relatively low, the fines content would be regarded as non-harmful
- If the MB value is relatively high, the fines content would be regarded as harmful
- Alternatively, the fines content may be considered non-harmful if the aggregate has been processed to conform with the fines content limit being imposed and demonstrated to produce concrete with satisfactory performance

Aggregate for concrete (Cont'd)

Relevant standards

- British Standard BS 882: 1992
- Euro Standard BS EN 12620: 2013
- BSI Published Document BSI PD 6682-1: 2009 Part 1
- Chinese Standard GB/T 14684: 2001
- Hong Kong Construction Standard CS3: 2013

Aggregate for concrete (Cont'd)

Limits on fines content in fine aggregates for concrete

Standard/ document	Limits on fines content
BS 882 and BSI PD 6682-1	9% for use in heavy duty floor finishes; 16% for general use
BS EN 12620	No limits applied
GB/T 14684	Natural sand: for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
	Manufactured sand: If the methylene blue test passes, for high strength concrete: < 3.0% for medium strength concrete: < 5.0% for low strength concrete: < 7.0%
	Manufactured sand: If the methylene blue test fails, for high strength concrete: < 1.0% for medium strength concrete: < 3.0% for low strength concrete: < 5.0%
CS3	10% for Class I (use in heavy duty floor finishes) 14% for Class II (general use and MB ≥ 1.4)

Aggregate for mortar

Relevant standards

- British Standard BS 1199: 1976
- British Standard BS 1200: 1976
- Euro Standard BS EN 13139: 2002/2013
- BSI Published Document BSI PD 6682-3: 2003
- Chinese Standard GB/T 14684: 2001
- Hong Kong Construction Standard CS3: 2013 (not applicable)

Aggregate for mortar (Cont'd)

Limits on fines content in fine aggregates for mortar

Standard/ document	Limits on fines content
BS 1199: 1976/ BS 1200: 1976	Crushed rock sand for rendering and plastering: 5% Type S sand for masonry mortar: 10% Type G sand for masonry mortar: 12%
BS EN 13139: 2002	Category 1 (floor screeds, sprayed, repair mortars): ≤ 3% Category 2 (rendering and plastering): ≤ 5% Category 3 (masonry with non-crushed aggregate): ≤ 8% Category 4 (masonry with crushed aggregate): ≤ 30%
BS EN 13139: 2013	Category f_3 : ≤ 3% Category f_5 : ≤ 5% Category f_5 : ≤ 8% Category f_{22} : ≤ 22%
BSI PD 6682-3: 2003	Levelling screed: ≤ 3% Rendering and plastering: ≤ 5% Masonry with Type S sand: ≤ 5% Masonry with Type G sand: ≤ 8%
GB/T 14684: 2001	Natural sand: < 5.0%
	Manufactured sand: If the methylene blue test passes: < 7.0% If the methylene blue test fails: < 5.0%

Aggregate for mortar (Cont'd)

Major issues in various standards

- Large variation in imposed limits on fines content
- Large difference in assessment of harmfulness of the fines content
- No established method for assessing the harmfulness of fines
- Usual practice is to impose limits on the fines content to reduce the possible risk of harmful substances
- Standards stipulated in CS3: 2013 on aggregates for concrete is not applicable to aggregates for mortar
- Separate standard required to limit the fines content on aggregate for mortar

Aggregate for mortar (Cont'd)

CIC studies

- Research on River Sand Substitute for Concrete Production and Cement Sand Mortar Production
- Phase One completed in 2013; Phase Two completed in 2015
- Fine aggregates for concrete may not be suitable as fine aggregates for mortar
- Need to establish a new construction standard on aggregate for mortar in Hong Kong
- Conducted plastering trials on the use of river sand and M-sand in mortar
- Drafted a Recommended Specification on Aggregates for Mortar (incorporated in CIC report)

Aggregate for mortar (Cont'd)

Trowelability of mortar

- Trowelability is best when the mortar is of the right wetness
- Dependent more on the water content rather than the fines content
- Smaller aggregate size of 2.34 mm is better than aggregate size of 5.0 mm
- No adverse effects on both trowelability and strength for fines content up to 8%
- No real necessity to impose limits of fines content in any fine aggregate for mortar
- Still consider advisable to limit the fines content at 5% to avoid large fluctuation

Aggregate for mortar (Cont'd)

Field plastering trials by experienced workers

- Judgement of trowelability very subjective
- Inaccurate batching; workers seldom weigh cement and sand contents
- Some workers tended to add more water for easier trowelling (smaller force)
- Some workers tended to add less water for better adhesiveness (larger force)
- Occasionally when too much water added, shrinkage cracks formed
- Developed a mini slump cone test for objective judgement of trowelability
- Pull-out tests conducted; bond strength similar whether river sand or M-sand used
- Need to provide training to workers for switching from river sand to M-sand
- Need to retrain workers to pre-wet substrate surface before plastering

Aggregate for reclamation

General Specification for Civil Engineering Works

- Clause 6.09: Fill material shall consist of naturally occurring or processed material, or, inert C & D materials, which is capable of being compacted
- Table 6.1: For fine fill material and general fill material, no fines content limit
- Table 6.1: For special fill material, a fines content of up to 45% is allowed
- Clause 21.12: Fill material for reclamation shall either be Type 1, Type 2, rock fill, or inert C & D material, or recycled rock fill
- Table 21.1: For underwater fill (Type 1), a fines content of up to 30% is allowed
- Table 21.1: For underwater fill (Type 2), a fines content of up to 25% is allowed
- Table 21.1: For rock fill material (grade 75), a fines content of up to 5% is allowed

Aggregate for reclamation (Cont'd)

Port Works Design Manual Part 1

- Clause 6.10: For underwater fill (Type 1), shall consist of natural material extracted from the seabed or a river bed, and is basically natural sand (i.e. not M-sand)
- Clause 6.10: For underwater fill (Type 2), shall consist of natural material, which has a coefficient of uniformity exceeding 5 and a plasticity index exceeding 12, and is basically decomposed granite or similar type of rock (i.e. not M-sand)
- Clause 6.10: For rock fill material (grade 75), shall consist of pieces of hard, durable rock which are free from cracks, veins, discolouration and other evidence of decomposition, and is usually used as levelling founding layers for marine structures (i.e. not for filling purpose)

Aggregate for reclamation (Cont'd)

Port Works Design Manual Part 3

- Clause 2.7.2: Rock and concrete over 250 mm would impede subsequent piling
- Clause 2.7.3: The maximum fines content (smaller than 63 μm) of the marine fill used in reclamation should always be less than 30% but for hydraulically placed fill, it is usually limited to about 10%

- GEO Report No.324
- Mentioned that Clean Washington Centre (CWC) imposed a maximum size of 19 mm and a fines content limit of 5%

Aggregate for reclamation (Cont'd)

Suspended solids limit imposed by EPD

- Waste discharge not to raise the natural ambient level by 30% nor cause the accumulation of suspended solids which may adversely affect aquatic communities

Comments by speaker

- Note that the above suspended solids limit is dependent on the ambient level of suspended solids, i.e. site specific
- The increase in suspended solids content is caused by the presence of fines content in the reclamation fill settling very slowly and sometimes even stirred up by turbulence
- Actual suspended solids content during reclamation is dependent also on the rate of filling, natural turbulence arising from tidal flow and wave, method of construction and effectiveness of silt curtains

Aggregate for reclamation (Cont'd)

M-sand as substitute of sea sand?

- With the use of sea sand containing about 1% fines content, the suspended solids pollution during reclamation is not a serious problem
- With the use of M-sand containing up to 10% fines content, the suspended solid pollution during reclamation could be a serious problem
- Should the reclamation fill have a maximum size of 200 mm, 75 mm or 20 mm?
- What should be the fines content limit of M-sand for reclamation?
- The allowable fines content has major effect on cost of production
- There is still no General Specification on Filling Material or M-sand for Reclamation

Aggregate for reclamation (Cont'd)

Possible development of M-sand for reclamation?

- To avoid contractual argument between the Contractor and the Supplier, there should be a clear standard of filling material or M-sand for reclamation
- Grades of filling material should be specified according to: maximum size of 200 mm, 75 mm or 20 mm; and fines content of 5%, 3% or 1%
- There may also be a particle size distribution requirement and a coefficient of uniformity requirement
- Balance should be made on the cost of improving the quality of M-sand and the cost of improving the method of construction to minimize suspended solids pollution
- Field trials should be carried out
- Consultation with the material suppliers, as represented by HKCMA, is needed

Conclusions

M-sand for sustainable development

- Due to depletion of natural river sand and sea sand, sand for concrete, mortar and reclamation will have to be manufactured from quarries as M-sand
- This helps to avoid pollutions and ecological hazards caused by dredging

Standards on M-sand

- However, sand for concrete, mortar and reclamation have different requirements
- There needs to be separate standards on sand for concrete, mortar and reclamation
- The current standard on M-sand for mortar is still just a recommended specification
- There is still no standard on M-sand for reclamation

Conclusions (Cont'd)

Reliable supply of sea sand for East Lantau Reclamation

- Huge quantity will be needed
- Sea sand supplies from China, Malaysia and Philippine rather limited and unreliable

Change to use M-sand for reclamation

- A standard is needed for the suppliers to follow
- Long term contracts with quarries operators needed because they have to set up equipment to process the crushed rock fine and find good ways to deal with the excess fines
- Local quarry and supply would improve reliability of M-sand supply

Thank you for your attention!